EE301 – FILTERS

Learning Objectives

a. Develop confidence in the use of logarithms and decibels in the description of power and voltage levels.
b. Become familiar with the frequency response of high- and low-pass filters. Learn to calculate the cutoff frequency and describe the phase response.
c. Be able to calculate the cutoff frequencies and sketch the frequency response of a pass-band or stop-band filter.
d. Develop skills in interpreting and establishing the frequency response of any filter.

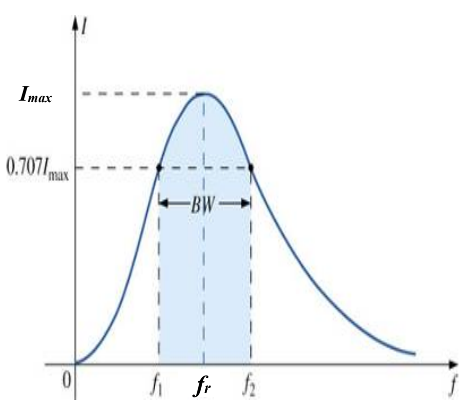
Filters

Filters are a natural application of series and (and parallel) resonant circuits. They are used extensively in communications applications to either select frequencies of interest or reject frequencies which interfere with the communications system.

How many antennas can you count on the superstructure of this ship?

Each antenna is part of a Radar or a wireless communications system which can potentially interfere with all of the other co-located systems. Some of the antennas are fixed and some rotate causing extremely high power to be directly pointed at adjacent receiving antennas.

This would be the equivalent of screaming into the ear of your roommate at the top of your lungs while they were asleep – it can permanently damage the receiving system. Your roommate can protect their ears with earplugs which *attenuate* (reduce) the sound prior to reaching the sensitive part of the ear – the eardrum. Filters do the exact same thing – they attenuate undesired interference and noise! The difference is that in communications systems the waves are electromagnetic instead of mechanical. Receivers are extremely sensitive just like the eardrum and must be protected from unexpected noise and interference.



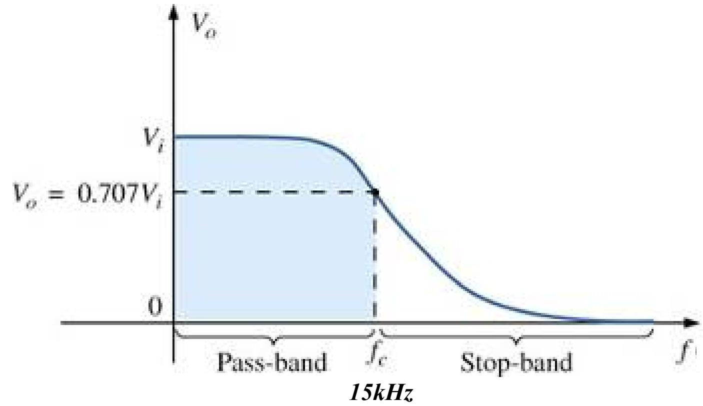
Band Pass Filter

Perhaps the most common type of filter in a receiver is a Band Pass Filter (BPF). These filters select (or "pass") the frequencies of interest and reject all other frequencies.

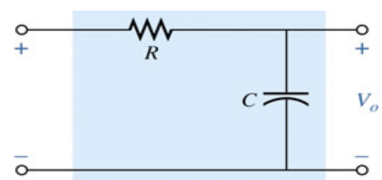
We've studied the series resonant circuit which has a frequency response characteristic similar to the one appearing in the figure to the right. Note that frequency varies on the horizontal axis while amplitude varies on the vertical axis. **This Series Resonant Circuit frequency response is identical to the typical Band Pass Filter response.**

Low Pass Filter

The Band Pass Filter is a very common part of most modern receivers. However there are many applications where some other type of filtering might make more sense. Low-pass filters are typically used to reduce high frequency noise in recordings or digital sampling operations (ie recording a conversation with your phone into an mp3 or other digital format), send only low frequencies to a woofer, or blurring photos. Calculating a moving average on the price of a stock is an example of a low-pass operation . The desired filter response might look like this:



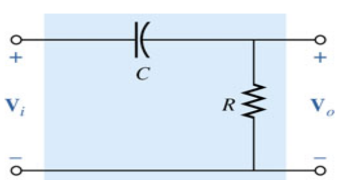
The ***cutoff frequency*** is the point at which higher frequencies are rejected. All the offending squeaky frequencies could be rejected! In reality, our brains do a lot of filtering in the 'post processing' stages of hearing. For example in a crowded, noisy room (like King Hall) when you 'focus' on what your friend across the table is saying, your brain is 'filtering out' all the offending background noise so you can hear the information you are interested in. This is pretty amazing! You might say that your ability to focus is actually your brain's ability to filter out interference – some filters are better than others! Modern receivers are also able to post process received signals and reject offending noise and interference.



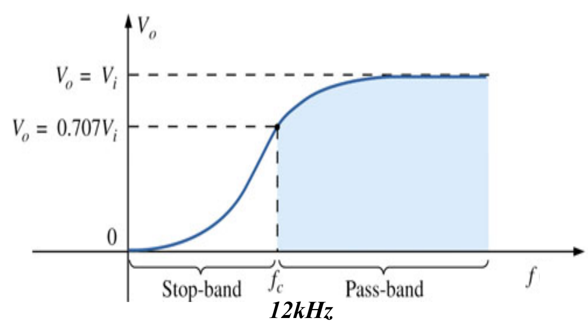
RC Low Pass Filter

High Pass Filter

High pass filters have many applications as well. High pass filters may be used to prevent low-frequencies from reaching an audio system tweeter, removing the DC component of a signal, or for sharpening photos.



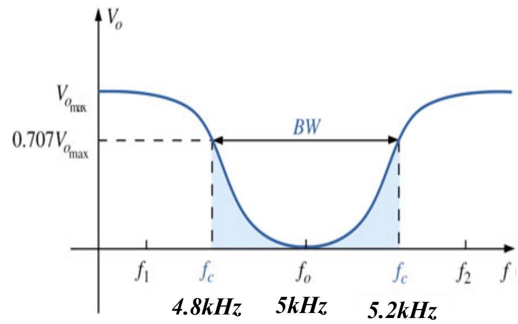
RC High Pass Filter



The ***stop band*** in all filters are the frequencies which are rejected and the ***pass band*** represents the frequencies which are passed through the system. It is important to be able to identify these on a given filter frequency response. We can build a high pas filter using only two components as shown.

<u>Band Stop Filter</u>

There is one final type of filter which is extremely useful. Let's return to the example of your roommate screaming in your ear. You can filter that offensive noise by using earplugs however, earplugs filter out *everything* and you need to hear your alarm clock in the morning. Instead of rejecting *all* frequencies we can simply measure the frequency of your roommate's voice and design a filter *specifically* to reject the frequency of his voice. That way you can hear everything else! If your roommate's voice has a frequency of 5 kHz +/- 200 Hz our filter would look like this:



The human brain is also capable of this type of filtering perceptions to some degree. If you ever visit a farm with roosters you'll likely in for a rude awakening the first few days but eventually you will filter that specific noise out. Removing these noises from your preception allows you to concentrate on other, perhaps more important, environmental factors (such as the ravenous tiger running toward you).

The Band Stop Filter is usually referred to as a *notch* filter because it is meant to 'notch out' or reject a specific frequency. This would be very useful in the VHF receivers on the ship pictured about where the Radar antennas spin around and inject extremely high power into the VHF receivers.

<u>Radio Spectrum</u>

The primary frequencies used in the US Navy are:

HF	3 to 30 MHz	High Frequency
VHF	30 to 300 MHz	Very High Frequency
UHF	300 to 1000 MHz	Ultra High Frequency
L	1 to 2 GHz	Long wave
S	2 to 4 GHz	Short wave
C	4 to 8 GHz	Compromise between S and X
X	8 to 12 GHz	Used in WW II for fire control, X for cross (as in crosshair).
Ku	12 to 18 GHz	Kurz-under
K	18 to 27 GHz	German Kurz (short)
Ka	27 to 40 GHz	Kurz-above

Filter Design

For both a low pass and high pass filter response we can find the inflection point called the cutoff frequency which is simply:

$$f_C = \frac{1}{2\pi\tau}$$

Where τ is the time constant we discussed in RC and RL circuits.

Example:

Design an RC Low Pass Filter for the HF band. Use a resistance of 10 Ω. Draw and label the frequency response.

Solution:

Example:
Design a series resonant RLC Band Pass Filter for the FM Radio Band (88MHz -108 MHz). Draw and label the frequency response. Which Frequency Band is FM Radio in?

Solution: